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Naval Stores Wastewater Purification and Reuse by Activated Carbon Treatment

Hercules, Inc, Hattiesburg, Miss

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This report documents the reasons for selecting a physico-chemical process instead of a more conventional biological process for secondary treatment of the complex organic wastewaters generated by a Naval Stores manufacturing plant. The selected carbon adsorption system is then discussed in detail including its removal effectiveness, problems encountered, and economics of operation. The system, when operated within specifications, is capable of removing about 80% of the COD and 85% of the TOC remaining after primary treatment at a cost of about 31.4¢/1000 gal. The total system achieves 95%+ removals of COD and TOC.

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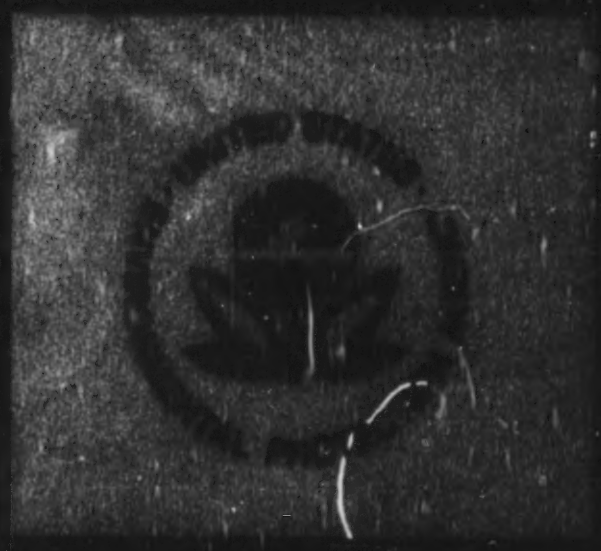

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NAVAL STORES WASTEWATER PURIFICATION AND REUSE BY ACTIVATED CARBON TREATMENT

by

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Grant No. S-801431

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report, "Naval Stores Wastewater Purification and Reuse by Activated Carbon Treatment", documents the full-scale evaluation of carbon adsorption for secondary treatment of complex industrial wastes. Although carbon adsorption has been used widely as a final polishing operation, very little attention has been given to its potential use in areas where biological treatment is less than desirable. In demonstrating that a system including such a physico-chemical process can remove more than 95% of the organic pollutants (COD) at a reasonable incremental cost for secondary carbon treatment (31¢/1000 gal), EPA has shown that viable, economical technology is available to meet current and even future discharge or receiving water standards without adversely affecting air or land quality. For further information on the subject, contact the Industrial Environmental Research Laboratory-Edison, NJ field station, 08817.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

A laboratory and pilot scale investigation of activated carbon adsorption for secondary wastewater treatment led to the installation of a system to provide treatment of a complex chemical plant wastewater. An up-flow, packed-bed adsorption tower design was chosen, and facilities were included to provide onsite reactivation of the spent carbon.

The adsorption system satisfactorily treated the wastewater for removal of dissolved organics at design loading, typically removing 79% of the influent loading as measured by TOC or COD. The adsorption system was not capable of removing large concentrations of suspended solids or oil and grease at design flow rates. The pH of the wastewater feed had to be neutral or slightly acidic to maintain an adequate removal of dissolved organics.

The multiple hearth furnace system installed for reactivation of the spent carbon proved to be very efficient and economical. Carbon losses through the furnace and the energy requirements of the system were found to be less than anticipated when compared to published information used in estimating the reactivation system operating cost.

The secondary treatment system required a capital investment of $1,422,000. During the 19 month period of this grant, operating cost averaged $30,186/month or 31¢ per 1000 gallons of water treated.

Based on the demonstrated total operating cost and treatment efficiency of the unit, it can be concluded that activated carbon adsorption is a feasible method for providing efficient secondary treatment of a complex chemical plant wastewater.

This report is submitted in fulfillment of Grant Number-S-801431 under the partial sponsorship of the Environmental Protection Agency. Work was completed as of January 31, 1975.

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SECTION I

INTRODUCTION

INDUSTRY BACKGROUND

Hercules Incorporated, Hattiesburg Plant, represents an industry that traces its beginnings to the time men first took to the seas in wooden ships. The Naval Stores industry takes its name from the fact that pine pitch was widely used for treating cordage and caulking wooden hulls in ancient times. One of the tasks of some of the early American Colonists was the production of pine pitch for use in England to maintain that country's far flung merchant fleet and navy.

The Naval Stores industry today produces materials finding a broad and much more sophisticated spectrum of uses--from chewing gum ingredients to insecticides, from floor polish resins to flavoring essences. The industry still obtains its raw materials from pine trees. Three methods of accomplishing this are: (1) collecting oleoresin from living pine trees, (2) extracting materials from the "fatwood" remaining from the stumps of previously harvested mature pine trees, and (3) collecting byproducts from paper mills using pine furnish for sulfate (kraft) pulping processes. These three sources lead to (1) "gum" rosin and turpentine, (2) "wood" rosin and terpene oils, and (3) "crude tall oil" (a mixture of resin and fatty acids) and "pulp mill liquid" (a mixture of terpene oils), respectively. Expanded background information and bibliographies are available in published form.[1]

HATTIESBURG MANUFACTURING OPERATIONS

The Hattiesburg operation uses raw materials from all three sources. Gum rosin and turpentine are purchased from primary manufacturers for further processing. Stumps, crude tall oil and pulp mill liquid are processed and refined to produce rosin and terpene oils. Rosin, turpentine, and terpene oils so produced are then chemically modified in a variety of processes to produce a diverse line of industrial chemicals. The various processes used include hydrogenation, disproportionation, polymerization, adduction, esterification, saponification, ethoxylation, and ammoniation to produce resins with enhanced properties. Terpene fractions may be marketed as such or further processed by hydrogenation, dehydrogenation, hydration, or oxidation to produce intermediate chemicals, alcohols, hydroperoxides, etc.

Operations carried out at the Hattiesburg Plant but not based upon raw materials of Naval Stores origin include production of a miticide, a

specialty synthetic rubber, hydrocarbon resins, and several chemicals for the paper industry including wet-strength resins, wax emulsions, and defoamers.

The plant has three sewer systems. Sanitary sewage is kept separate from all other wastes and is delivered to the City of Hattiesburg sanitary sewage system. Waste cooling water (non-contact) is discharged to a system which bypasses the wastewater treatment unit. Contaminated wastewaters from the various processes, including process area surface drainage, are collected through a system of sumps and lift stations for delivery to the wastewater treatment area. Where feasible, process area sumps and lift stations include provisions for on-the-spot removal of settleable solids and/or floating oils.

Measurement of the various process area wastewater flows is not presently instrumented. Flows are measured from time to time as needed by manual means appropriate to the particular area. In most cases flows are calculated from timed accumulation in sumps.

To determine the area wastewater contamination levels, grab samples are secured from each process area three to five times a week until at least twelve samples have been taken. Samples are analyzed the same day they are caught. Free oils and settleable solids are removed by decantation and the Total Organic Carbon (TOC) content is determined with a Beckman Model 915 TOC Analyzer. Results from the 12 samples are averaged. This procedure is repeated from time to time as needed to keep the data current. It is important to note that these analytical data do not include those oils and solids which are readily separable by decantation. The analytical measurements include dissolved organics plus suspended and/or emulsified organics.

A breakdown of area flows and Total Organic Carbon contents is shown in Table 1. This kind of information has been invaluable in guiding in-plant pollution abatement efforts and in distributing treatment costs to the product cost centers.

TABLE 1. PROCESS AREA WASTEWATER FLOW AND ANALYSIS

Process area	Flow, gpd	Total organic carbon content* mg/l	lb/day	% of Total	
Stump processing	258,000	1,160	2,500	23.9	Basic processes 41.9%
Tall oil processing	184,000	1,110	1,700	16.2	
Pulp mill liquid processing	19,800	1,150	190	1.8	
Terpene hydration	110,000	220	200	1.9	Modification processes 41.4%
Rosin hydrogenation	550,000	240	1,100	10.5	
Rosin polymerization	252,000	275	580	5.5	
Rosin disproportionation					
Rosin saponification					
Rosin adduction	500,000	150	625	6.0	
Rosin esterification					
Rosin salts					
Rosin ammoniation	306,000	720	1,830	17.5	
Ethoxylation process					
Terpene dehydrogenation					
Terpene oxidation					
Petroleum resins					
Miticide	75,000	1,070	670	6.4	Non-naval stores operations 16.7%
Paper chemicals	100,000	240	200	1.9	
Synthetic rubber	43,000	500	180	1.7	
Miscellaneous	194,200	435	700	6.7	
Totals	2,592,000	485	10,475	100.0	

*After removal of free oils and settleable solids. Represents contaminants present as dissolved organics and finely dispersed and/or emulsified oils.

PRIMARY WASTEWATER TREATMENT

The wastewaters from the various processes are delivered to a common wastewater treatment area, shown in Figures 1 and 2. The water first enters an impounding basin installed in 1951 to provide 5-6 hours retention time for equalization and preliminary clarification. Overflow and underflow baffles permit floating oils to be removed by a skimmer and settled solids to be removed periodically by dredging.

The pH of the mixed wastewaters in the impounding basin is normally about 3-4. This low pH was found to be very desirable since it minimizes foaming and emulsification and reduces the solubility of the organics contained in some of the waste streams, thus enhancing performance of the primary treatment system.

Because of the preliminary clarification accomplished in the impounding basin, the Total Organic Carbon content of the exit water is well represented by the totals shown in Table 1 (area flows and analysis) which, as described earlier, resulted from analysis of partially clarified samples. The impounding basin exit water still contains suspended and emulsified organics, however, which are removed in the next treatment stage, the air flotation clarifier.

The dissolved air flotation clarifier, installed in 1972, is 52 ft in diameter and operates at 8.5 ft water depth, with a rated capacity of 4.32 mgd. Following the clarifier is a two-stage pH adjustment system using 50% aqueous NaOH to bring the pH up to 6-7.

Typical primary treated wastewater analyses are shown in Table 2. These results were obtained on daily composites made up from grab samples caught every two hours (12 samples per day). With average inlet TOC of 485 (Table 1), the average outlet TOC of 193 (Table 2) indicates a contaminant level reduction of 60%. At the normal flow rate of 2,592,000 gpd, the air flotation clarifier is indicated to remove 6,300 lb/day of TOC.

Oils recovered from the impounding basin and clarifier are utilized as fuel in the main plant Power House, thus recovering fuel value. Solids from the impounding basin and clarifier are presently disposed of by landfill (private contractor), but we expect to eventually develop the capability of recovering fuel value from this material also. Laboratory investigation indicates that dewatering, by adding a light fuel oil, for example, produces a readily combustible product.

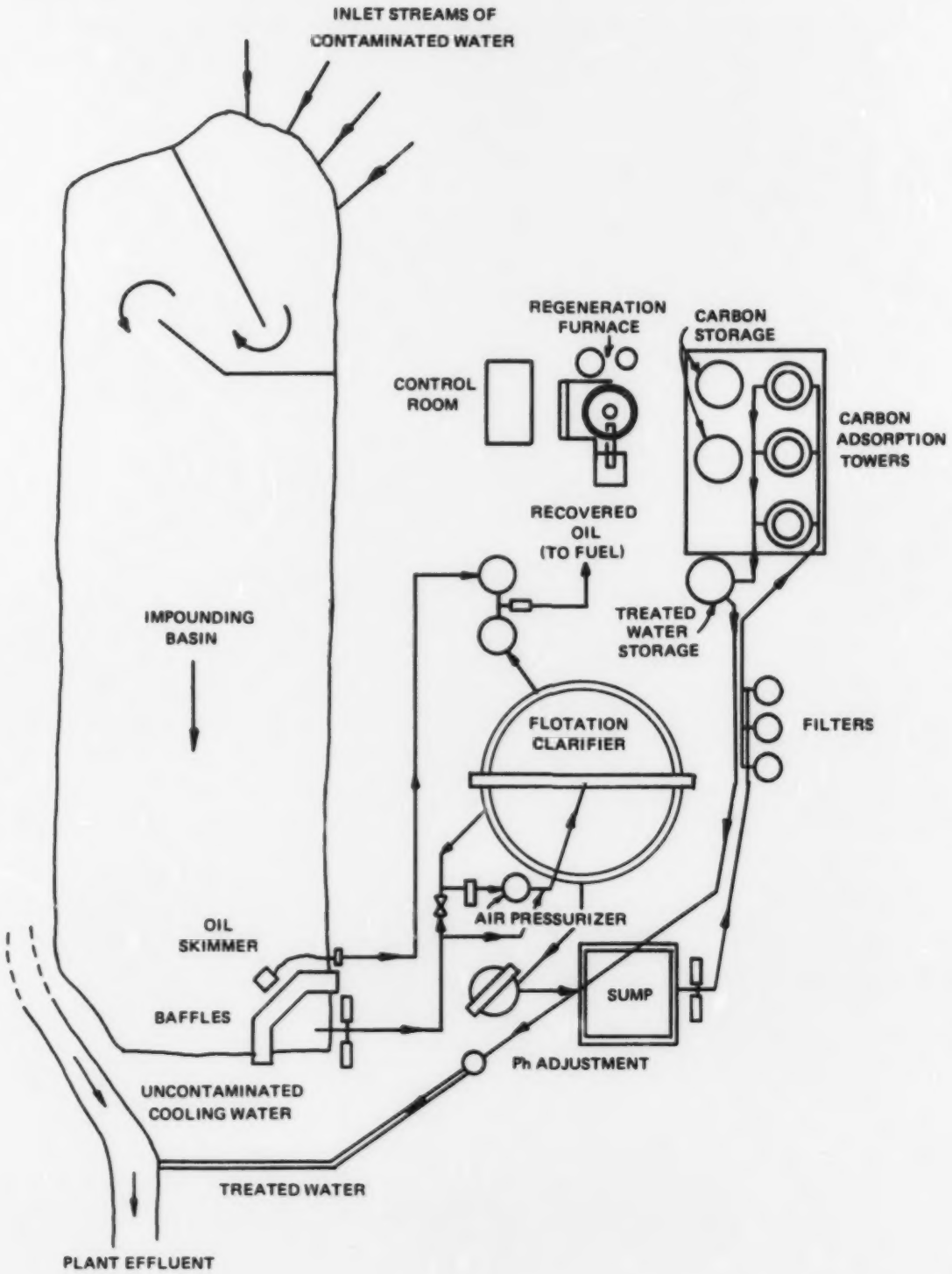

Figure 1. Wastewater treatment area layout.

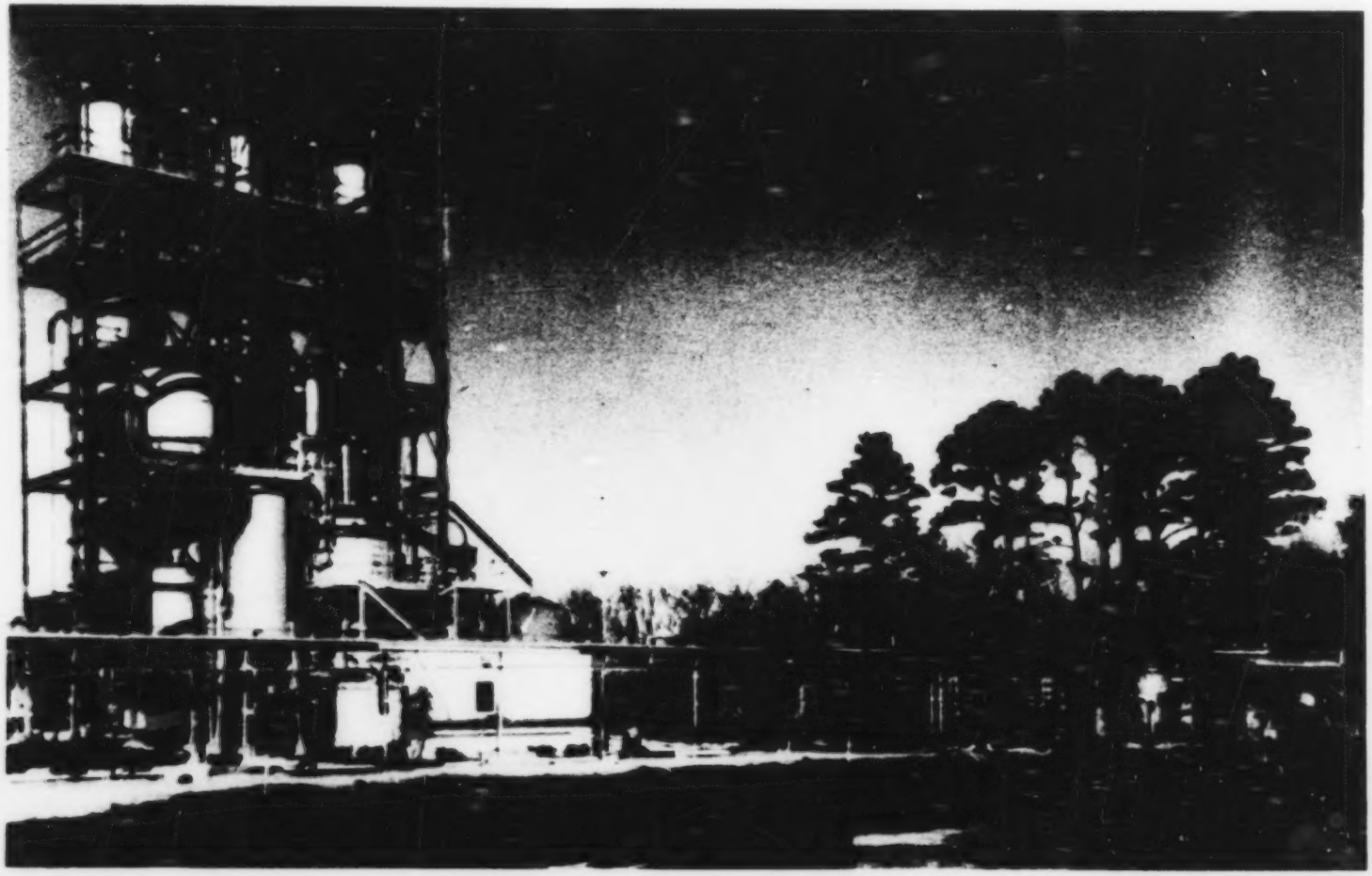

Figure 2. Wastewater treatment area photograph.

TABLE 2. PRIMARY TREATED WASTEWATER ANALYSIS

Date, 1973	pH	mg/l COD	TOC
9/4	8.0	704	221
9/7	8.1	648	191
9/10	6.6	896	235
9/25	6.9	560	168
9/26	7.9	641	192
10/1	6.8	720	149
10/2	6.6	576	183
10/3	7.1	640	169
10/4	6.0	1077	200
12/5	6.0	800	221
12/6	6.0	960	265
12/10	7.4	688	175
12/17	6.0	624	167
12/19	7.2	448	171
Avg.	6.9	713	193

Performance of the primary system has been generally satisfactory. As mentioned earlier, the pH in the impounding basin and clarifier should be about 3-4 and the unavoidable occasional excursions above this range impair the performance of the system. Work is in progress to provide a control system to overcome this difficulty.

ENVIRONMENTAL EFFECTS

Treated effluent from the Hattiesburg Plant is discharged to a city drainage ditch which leads to the Bowie River (a tributary of the Pascagoula River System). At Hattiesburg, the Bowie River empties into the Leaf River, which joins the Chickasawhay River near Merrill, Mississippi, to form the Pascagoula River.

This is a more or less typical coastal river system with normally murky, often muddy water and large flow variations. It is used for recreational fishing and boating, and in the lower reaches (below Merrill) for commercial fishing.

The Leaf River receives municipal wastewaters from the cities of Hattiesburg and Laurel and industrial wastewater from the Masonite Corporation plant in Laurel in addition to Hercules' wastewater.

The river system has been surveyed from time to time by various groups. A survey made in 1961-1962 by the Mississippi State Game and Fish Commission reported: "The dilution ratio is such in the Hattiesburg area that a complete deoxygenation of the stream is probably never accomplished but the water quality is altered to the extent that it is not in the optimum range for normal aquatic conditions to exist for approximately a twelve-mile section of the stream".[2]

Extensive data are to be found in the "Pascagoula River Basin Water Quality Management Plan" developed by Pat Harrison Waterway District in 1973.[3]

The consensus seems to be that the river system assimilates these wastes without disastrous effects but not without quality deterioration. There have been fish kills in the system, but most have been attributed to natural (or unknown) causes. There have been none directly attributable to Hercules' waste discharge within the experience of the authors (approximately 20 years). The nature of the contaminants in the Hercules wastewater is such that they have oxygen consuming potential, but there is no evidence that toxicity to aquatic life is a problem at the dilution levels existing.

In recent years, abatement efforts on the part of all the major dischargers have resulted in measurable improvement in the river quality. Dr. B. J. Grantham, a Marine Biologist at the University of Southern Mississippi at Hattiesburg, was quoted in the Jackson Clarion Ledger (daily newspaper) on March 30, 1973, as stating that the upper region of the Pascagoula River "is becoming one of the cleanest stretches of water in the Nation". This observation predates the startup of the secondary treatment process which is the subject of this report.

SECTION II

CONCLUSIONS

An activated carbon adsorption system is capable of providing secondary treatment of a complex chemical plant wastewater for removal of dissolved organics provided certain design criteria are adhered to.

Overall removal of dissolved organics from the wastewater as measured by COD, TOC, and BOD was typically about 79 per cent during periods of steady state operation with design feed conditions. Reduction across the total system amounted to >95 per cent.

Make-up carbon required to replace the carbon lost in the handling and regeneration cycles amounted to 3-5 per cent per cycle. A treatment cost (ex-depreciation) of 31.4¢ per thousand gallons of water was achieved during the evaluation period. During steady state operating periods when the wastewater feed was similar to design quality, a COD removal cost (ex-depreciation) of 6 cents per pound of COD was achieved.

The regenerated carbon was found to be slightly more active for removal of organics from the plant wastewater than virgin carbon. This phenomenon can be attributed to the fact that the organics in this wastewater stream are adsorbed in the larger pores, and during reactivation of the carbon many of the smaller pores are fractured to create a higher proportion of large pores per unit weight of carbon.

With a high Btu value organic load such as present at this plant, fuel requirements for carbon regeneration were significantly lower than expected.

An up-flow, packed-bed adsorption system provides maximum use of the activated carbon and minimizes carbon inventories. This type of system does have certain limitations in that the wastewater feed cannot contain more than 10 ppm of suspended solids or 15 ppm of oil and grease without causing a high pressure drop across the carbon bed which, in turn, makes premature pulsing or slugging of the carbon bed necessary.

A build-up of carbon fines in the system occurs after the carbon has gone through many regeneration cycles, and this leads to high bed pressure drop problems. Purging of fines by back-flushing the regenerated carbon storage tank with water satisfactorily corrects this problem.

When pulsing the carbon bed and after completely filling an adsorber, carbon fines will show periodically in the treated effluent. Provision for re-

cycling carbon-contaminated effluent is necessary.

Biological activity also occurs in the carbon beds at times, which increases the carbon bed pressure drop but also increases the efficiency of the system for removal of dissolved organics. If the bed contact time of the wastewater is long enough to deplete the dissolved oxygen in the water, the biological activity becomes anaerobic. When this happens, the treated water develops a characteristic unpleasant odor.

The pH of the feed wastewater must be maintained below a maximum of 7.5 to provide efficient removal of dissolved organics. If the pH is above 7.5, the treatment efficiency drops off in proportion until reaching a pH of approximately 9. When the pH is above 9, the treatment efficiency drops almost to zero. COD loadings on the carbon of 0.9 pounds COD per pound of carbon were achieved during operating times when a high bed pressure drop was not the controlling factor in determining when the bed had to be pulsed. During periods when there were pressure problems, a COD loading of 0.63 pounds COD per pound of carbon was achieved.

Equipment and piping designed for handling carbon/water slurries should not be constructed of carbon steel but should be either stainless steel or epoxy fiberglass to avoid serious corrosion problems.

The activated carbon system also removes a portion of certain metal contaminants in the wastewater.

Activated carbon adsorption is acceptable for providing secondary treatment of a wastewater stream, but as for most systems, it cannot continuously be overloaded and expected to produce the same quality effluent. The system will provide a defined capacity for removal of dissolved organics even under overloaded conditions.

SECTION III

RECOMMENDATIONS

Additional performance data are needed under steady state operating conditions to determine accurately the pressure drop characteristics for activated carbon loaded with an organic waste that is oily in nature. This information should be provided before a system is designed for treatment of this type of wastewater stream.

Before an up-flow packed-bed adsorption system design is chosen for treatment of a wastewater stream, it should be established that adequate control of the suspended solids, oil and grease, and pH of the feed is provided. In short, an activated carbon secondary treatment system must be preceded by an effective primary treatment system if the total unit is to be economically and technically acceptable.

Investigation should be undertaken to develop an activated carbon adsorption system that takes advantage of the biological activity that occurs in the carbon bed.

The design of a carbon adsorption system should include facilities in the process for removal of carbon fines that build up in the system after successive regeneration cycles.

All piping or equipment that remains in contact with the activated carbon water slurries should be stainless steel or fiber glass.

SECTION IV

DISCUSSION

SECONDARY TREATMENT PROCESS DEVELOPMENT

In planning for secondary water treatment it had long been thought that we would follow the time-honored path of biological processing. As the time of decision drew nearer, the problems we anticipated with a biological system loomed ever larger. The land area which would be required was available only on the wrong side of the plant which now finds itself within the residential portion of the city. In a pollution sensitized community, the odor-producing potential of the system would be frightening. Nobody really seemed to have satisfactory solutions to the problem of biological sludge disposal.

In preliminary discussions with city officials there appeared to be little interest in joint treatment facilities. One discouraging aspect was that the Hercules Plant and the city's treatment area are on diametrically opposite sides of the city and a new sewer main would be required for the entire distance.

We knew that carbon adsorption had established utility for tertiary treatment and that a few secondary treatment systems were in operation or being planned. We therefore undertook laboratory experiments to see how effective carbon might be on our wastewater stream.

In our laboratories, carbon isotherms revealed that carbon was indeed effective on our wastes, and adsorption of 0.85 lb COD/lb carbon was indicated. This was a higher loading than we had been led to expect, so we obtained independent confirmation from other laboratories. Hercules' Environmental Services Division's laboratory in Houston, Texas found an adsorption of 1.2 lb COD/lb carbon, and Calgon Corporation, Pittsburg, Pa., found an adsorption of 1.0 lb COD/lb carbon. Results of the three studies are shown in Figure 3.

With the encouragement of high adsorption potentials, we constructed a pilot plant to test continuous granular carbon treatment of wastewater drawn from the plant impounding basin. A photograph of this unit is shown in Figure 4.

The dissolved air flotation clarifier portion of the primary treatment system described earlier was still under construction when this work was undertaken, so a small scale clarifier was included in the pilot plant. The pilot unit was also equipped for pH adjustment and filtration through "pea" gravel in

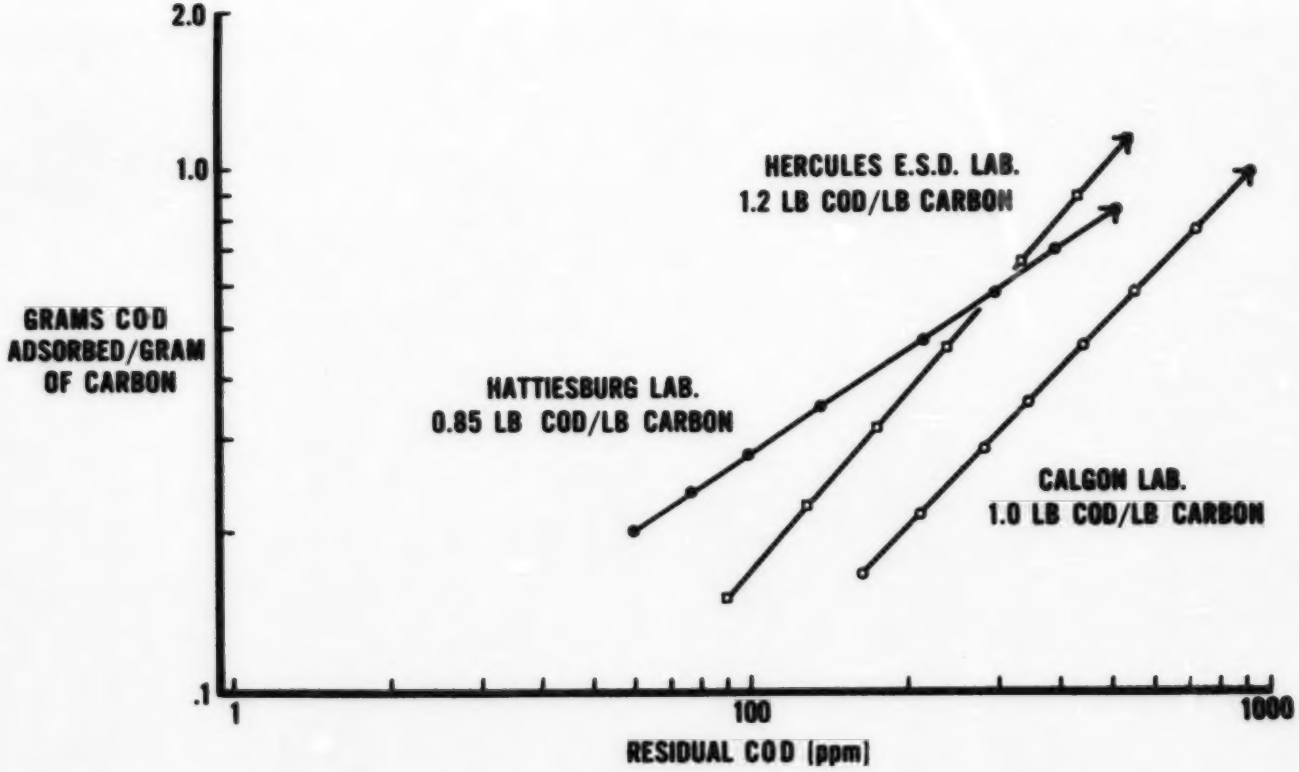

Figure 3. Carbon isotherms (Calgon Filtrasorb 400).

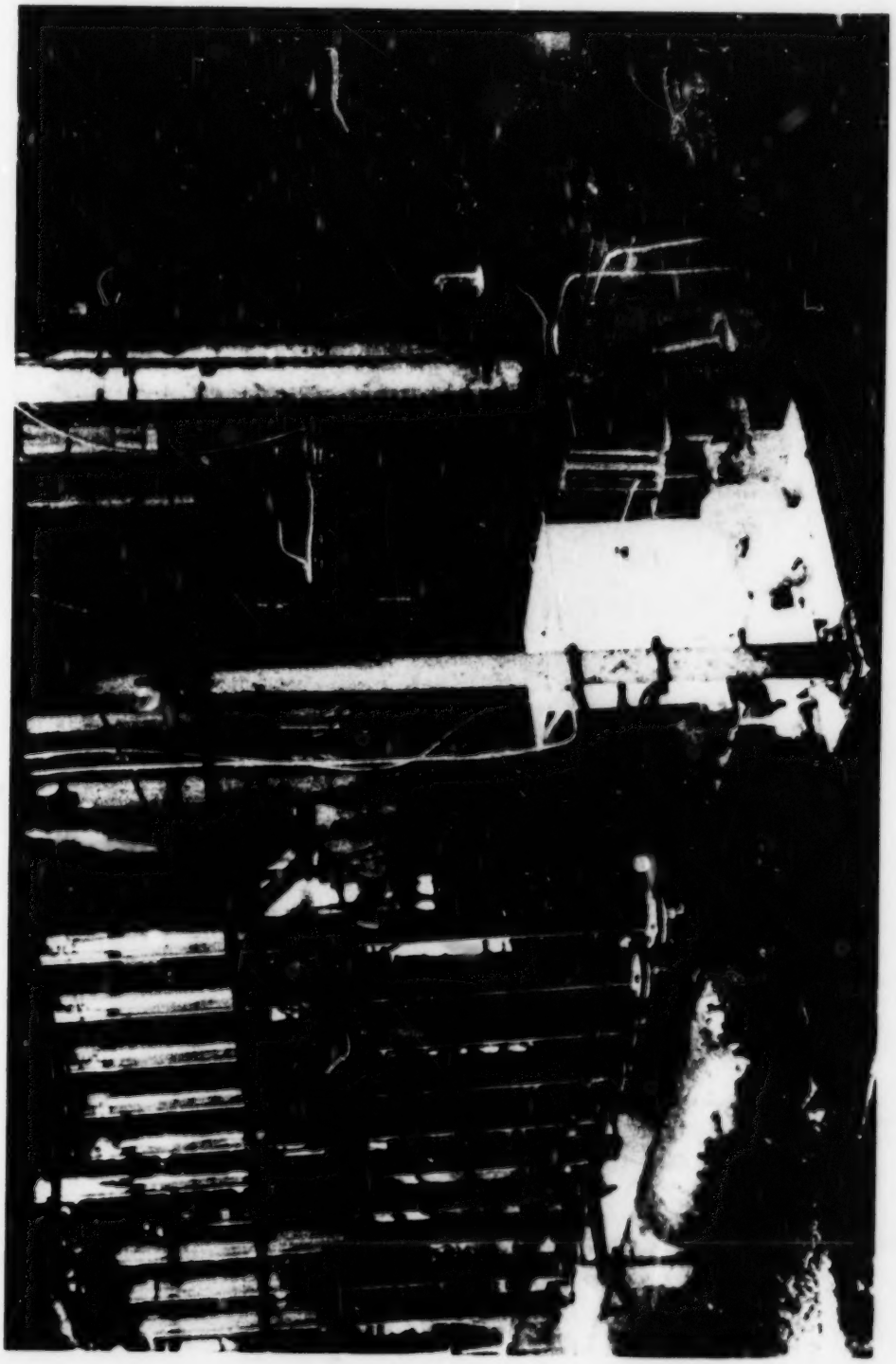

Figure 4. Carbon adsorption pilot plant.

addition to carbon treatment. The carbon treatment columns were 3-in inside diameter Pyrex glass pipe sections 5 ft long packed with 4.4 lb each of Filtrasorb 400 carbon (Calgon Corporation).

The unit was operated for a total of 52 days exploring the effects of flow direction (up vs. down), irrigation rate, and contact time. Conclusions drawn from this work were as follows:

1. Upflow vs. downflow.

   We found that treatment efficiency was approximately the same either way. The upflow pattern is more tolerant of suspended solids in the feed water and, with slight bed expansion (5% max.), lower pressure drops can be obtained. As irrigation rate is increased, however, bed expansion rises sharply and carbon losses due to attrition and decantation became significant. The relationship between bed expansion and irrigation rate varies with carbon source and condition (organic loading). Downflow operation, because of the filtration effect of the bed, requires periodic back washing and pressure drop will average slightly higher than for expanded bed upflow, increasing as the unit approaches the need for backwash.

2. Irrigation rate.

   Downflow irrigation rates of 3-5 gpm/sq ft were evaluated and found satisfactory. An upflow irrigation rate of 3 gpm/sq ft was satisfactory, but 5 gpm/sq ft resulted in excessive bed expansion and carbon losses.

3. Contact time.

   Contact times between 45 and 50 minutes (based on settled bed volume) were found to give COD removals of 75-85% within the range of irrigation rates found satisfactory.

4. Carbon loading.

   The COD loadings found by isotherm were confirmed in these tests. In two tests run to carbon exhaustion, loadings of 1.03 and 0.96 lb COD/lb carbon were obtained.

The COD removal performance of the pilot plant unit during one of the downflow tests is shown in Figure 5.

Having in hand the basic information needed to design a carbon adsorption secondary treatment unit we faced one more hurdle. The common wisdom of the day (1970) said that a carbon unit would be significantly more expensive to build and operate than a biological unit. To clarify this issue we constructed and operated a biological treatment (activated sludge) pilot plant. The basic design and operating parameters were provided by a Hercules subsidiary, Black, Crow and Eidsness, Inc., of Gainesville, Florida. The unit

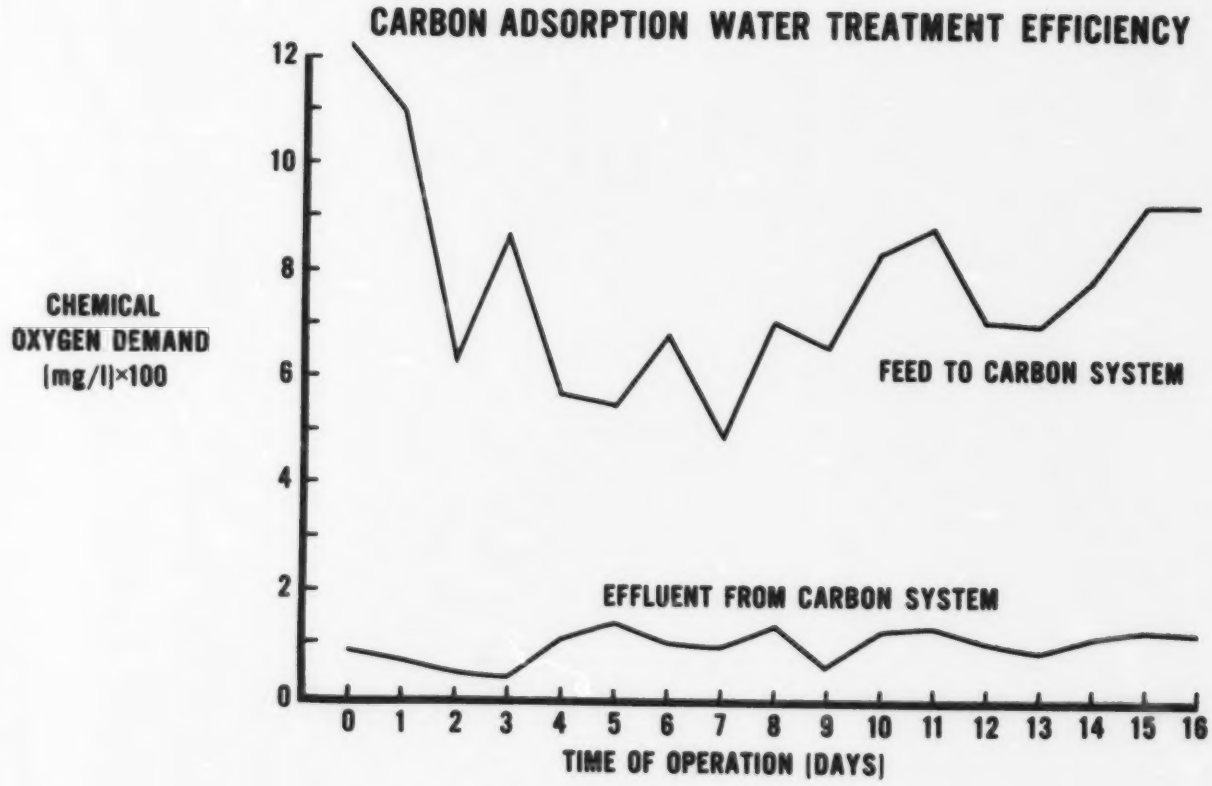

Figure 5. Pilot plant performance.

was built to process 5 gph of primary treated water with the following operating conditions: 72 hr equalization of the primary treatment effluent, 10.5 hr aeration contact time, pH 6.5-7.5, clarifier settling time 3.6 hr at 600 gpd/sq ft, 5 gph (1/1) recycle of clarifier bottoms, and mixed liquor volatile suspended solids level of 2,500 mg/l - total suspended solids level approximately 3,600 mg/l. The pilot biological unit was operated for a period of 28 days with quite variable performance, but a treatment efficiency of 75% was demonstrated.

Armed with basic design data for carbon and biological treatment systems, we obtained preliminary construction and operating cost estimates for units of both types to treat the total plant contaminated wastewater, 2.6 mgd, as follows:

Estimated cost:

	System Type	
	Biological	Carbon Adsorption
Construction.....	$2,013,808	$1,781,000
Operation (annual).....	170,493	181,623

These estimates were interpreted as indicating that the choice of type of system need not be influenced by cost but could be made on the basis of other considerations. The carbon system was therefore chosen, primarily on the basis of greater flexibility, tolerance of feed variations, and better quality water output (particularly better color and lower suspended solids). In addition, carbon is not affected by chemicals which might be toxic to biological systems. Although we did not encounter problems with toxicity in our evaluation of biological treatment, we felt it to be a threat because of the wide variety of chemicals used and produced in the plant. Protection from this threat would necessitate extended pre-treatment equalization, requiring land area not readily available.

TREATMENT UNIT DESIGN

Having settled on carbon adsorption as the system to be used, in-depth engineering design studies were undertaken. Various aspects of the design studies are discussed below and the final design flowsheet is shown in Figure 6.

1. Prefiltration.

The effluent from the primary treatment system (after pH adjustment) was found to contain about 50 mg/l of suspended solids. Tests indicated that a high-rate downflow mixed media filter would reduce this to 5 mg/l. The solids removed were oily in nature and their removal reduced the TOC of the water by an amount equal to the solids removed (45 mg/l). Conventional backwashing plus air scouring was found satisfactory for removing solids collected in the filter and controlling pressure buildup. The backwash water could be clarified by dissolved air flotation and therefore, could be recycled through the primary treatment system. Basic filter parameters

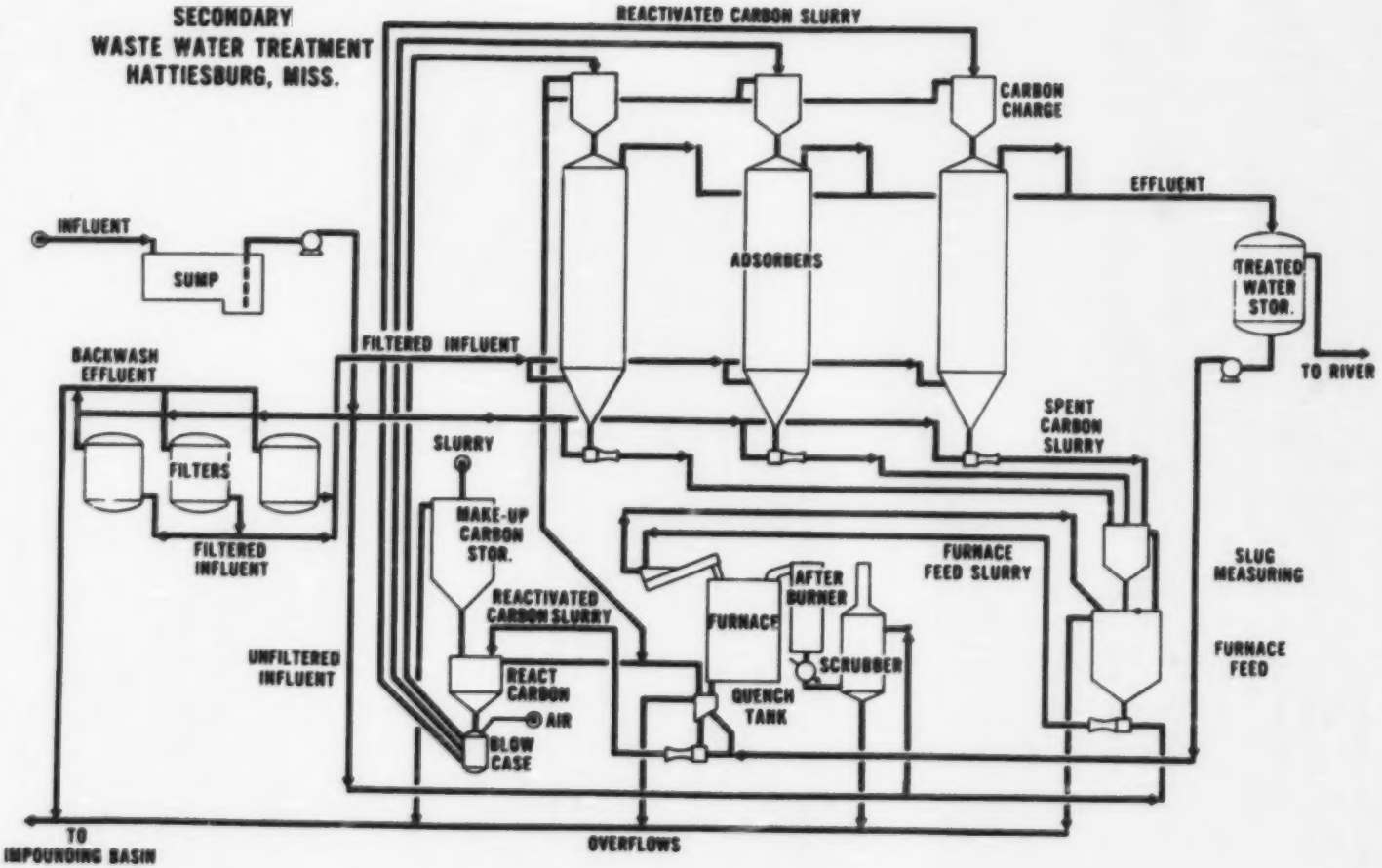

Figure 6. Carbon adsorption design flow sheet.

were: high rate downflow type, 13 gpm/sq ft feed rate, 3 to 8 backwash cycles/day composed of 30 second air scour at 3 cu ft/sq ft, 1 minute settling time, and 5 minute backwash at 15-18 gpm/sq ft. In the final design, three filters (parallel flow) were provided and they were to operate under full system pressure, being located in the flow line between the system feed pumps and the carbon adsorption towers.

2. Carbon adsorption towers.

The adsorption system chosen in the design studies was the up-flow, packed, bed type.[4] This type of system was found to offer lower construction cost and greater flexibility in operation. A countercurrent flow pattern was chosen because more efficient use of the carbon results since this system approaches that of a continuous countercurrent operation when the rate of carbon bed pulsing is properly designed. Three adsorbers to be operated in parallel were chosen because of the economics of vessel construction and shipment cost. Each adsorber was to operate at a minimum bed contact time of 44 minutes at a maximum cross section flow of 7.35 gpm/sq ft. The adsorbers are designed for an average contact time of 48 minutes at a cross section flow of 6.6 gpm/sq ft. The carbon pulsing system is designed to remove approximately 5% of the carbon bed daily from the bottom of the adsorber while regenerated carbon is charged at the top. All carbon transfers are made while the carbon is in a water slurry. External design data for this type of carbon adsorption system can be found in the U.S. Environmental Protection Agency Technology Transfer Manual on Carbon Adsorption.[5]

3. Spent Carbon Reactivation.

The spent carbon is dewatered to approximately 50% water by weight with an inclined dewatering screw and discharged by gravity into a multiple hearth furnace for reactivation. The furnace is a 5 hearth 12 ft OD unit capable of reactivating 33,600 pounds of carbon per day. In the furnace, the damp carbon is dried and heated to 1,600-1,800 °F with three burners on each of two hearths (#3 and #5). The burners are normally fired with natural gas but can be fired with #2 fuel oil if necessary. Supplemental steam is added to the furnace to control the reactivation atmosphere at a ratio of one pound steam per pound of carbon and the hot gases flow countercurrent to the flow of the carbon. The furnace system is designed to be operated by automatic controls and with safeguards to permit unattended operation. An after-burner is included in the furnace design to remove objectionable odors and to insure complete combustion of the organics in the furnace off gases.

The exhaust gases then pass through a wet scrubbing system for cooling and removal of particulate matter before being discharged to the atmosphere. This system is designed to meet current air pollution laws. The scrubber discharge water is returned to the primary treatment impounding basin.

4. Overall design performance parameters.

The overall design performance parameters for the secondary treatment system were:

Performance parameters:

	Influent	Effluent
System flow, mgd	3.35	---
Net flow, mgd	---	3.24
COD, mg/l	700	125
TOC, mg/l	200	30
BOD, mg/l	250	50
SS, mg/l	50	<5
DS, mg/l	650	400
Oil and grease, mg/l	25	5
pH	6-8	6-8
Temperature, °C	36	36
Carbon flow, lb/day	21,000	
Carbon loss, lb/day	1,050	

TREATMENT UNIT PERFORMANCE

The performance of the activated carbon adsorption system chosen for treatment of the plant wastewater will be described in two phases; 1) an evaluation of process equipment with recommendations, and 2) an evaluation of the process performance with recommendations.

1. Evaluation of Process Equipment.

When the waste treatment system was started up it was noticed that the operation of the mixed media filters was very rough during a backwashing cycle. The primary cause of the problem was the high operating pressure of the filters (175 psig inlet) in conjunction with the abrupt opening and closing of the butter-fly valves used on the filter. Within 48 hours of operation start-up the discharge laterals in the filters collapsed allowing the garnet in the filters to be washed out with the water. The garnet flowed into the carbon adsorption towers with the wastewater where it mixed with the activated carbon. As carbon was slugged from the towers and processed through the reactivation furnace portions of the garnet melted and plugged up the furnace. In the various carbon handling systems the garnet eroded the transfer eductors and eroded the flow control valves to each adsorption tower. After the failure of another set of discharge laterals, the problem was diagnosed to be due to the filter bed settling as a plug on the unsupported laterals which then collapsed. The original laterals which were ABS plastic were replaced with stainless steel wire laterals supported internally with slotted stainless pipe. The valve operation on the filters was smoothed out by placing needle valves on the operating air supply lines which could be adjusted to provide a smoother slower opening cycle. Since these modifications were completed, the automatic operation of these filters has been very dependable and designed operating parameters for the units are easily attained.

The carbon adsorption unit consists primarily of three sections, the carbon adsorption towers, the carbon storage and handling system, and the spent carbon reactivation furnace system.

The carbon adsorption towers are constructed of 316 stainless steel and no corrosion problems have been observed. The only alterations in the tower design have been to provide internal supports for the effluent screens to prevent them from bending during slugging operations when an air pocket rises through the adsorption tower and to replace the rupture disc pressure control system with a vented stack pipe overflow system to handle sudden surges in the water feed rate. The inlet and discharge piping was installed with welded joints and carbon steel pipe was used. For handling the feed water to the adsorbers the steel pipe is holding up satisfactorily but the discharge piping has been replaced with fiber glass and stainless steel pipe. The carbon fines which escape with the treated water caused severe erosion and galvanic corrosion problems at all elbows, welds and the bottoms of straight run pipe sections. Both the stainless and fiber glass pipe appear to be holding up satisfactorily.

The tanks used in the handling and storage of the activated carbon are constructed of stainless steel and are providing satisfactory service. The carbon transfer pipe system was originally constructed of mild steel pipe but as was the case for the adsorber effluent piping it is being replaced with stainless pipe. Where turns are made in the transfer of carbon slurries, long-sweep rubber sections of pipe were originally used. These joints do not have any longer life than if the joint were constructed from carbon steel. It is recommended that all carbon transfer piping be of stainless steel and that long sweep stainless steel elbows be used for direction changes. To move the carbon slurries, the water powered eductors have proven to be very satisfactory if constructed from stainless steel.

In the original design, no provision was made for removal of carbon fines which accumulate in the system after successive regeneration cycles. To correct this problem, a water sparge ring was installed in the reactivated carbon storage tank so that accumulations of fines could be flushed out of the system and back to the primary treatment unit.

As previously described, a multiple hearth furnace system was constructed for reactivation of the spent carbon. This unit has proven to be very capable of reactivating spent carbon at design rates and conditions. The unit was shut down and restarted on many occasions during the start-up of the wastewater treatment system when failures in the laterals of the mixed media filters occurred. The furnace system was performing well until recently when sections of the brick which make up the #1 hearth started buckling up until the rabble arm teeth broke them loose. The bricks caused severe erosion of the rabble arm teeth and caused cracks in the rabble arms of the remaining four hearths. This problem appears to be a common one since other industries with similar furnace systems have had similar problems occur recently. Initial studies indicate this problem to be due to the high moisture content of the spent carbon as it is charged to the first hearth. To keep the unit in operation, the furnace was shut down and the remaining bricks in the damaged hearth were removed. At the writing of this report, the proper repair of the rabble arms and teeth cannot be made until new parts are obtained from the furnace manufactuer. The furnace was placed back in operation with very badly damaged rabble arms and three effective hearths, but it is still producing high quality reactivated carbon at

reduced feed rates.

We recommend that a furnace system such as this one be shut down at least every 3 months for an inspection of the brickwork and rabble arms and teeth and that a ceramic coating recommended by the manufacturer be applied to the brickwork surface in the first hearth. This coating reportedly aids in preventing a failure of the brickwork due to the high moisture content of the spent carbon. We understand that this coating has proven satisfactory for furnaces operated by Calgon Corporation for reactivation of spent carbon.

2. Evaluation of Process Design and Performance.

The performance of this activated carbon adsorption system for treatment of the plant wastewater is summarized in Tables 3 and 4, Figure 7, and detailed in Appendix B. The time lapses between periods of data compilation represent times when operation of the system was impaired by mechanical problems as previously described.

During the period the secondary water treatment facilities were under construction, additional work was completed to segregate uncontaminated water from the plant wastewater sewer system resulting in an overall reduction of flow. Although the flow was reduced 11%, the level of organic wastes in the water increased during this time.

The water treatment facilities were started up during a period when the plant wastewater contained 35% more dissolved organics than the system was designed to remove. The carbon towers were initially capable of handling this additional load since the carbon was completely fresh.

Reductions in the COD and TOC of the wastewater of 84 and 79 per cent respectively were obtained by the carbon system. During this period, carbon loadings of 1.2 lb COD per pound of carbon and 0.44 lb of TOC per pound of carbon were realized. The system was shut down at times for mechanical repairs to the mixed media filters and it was observed that biological activity was occurring and that this activity could have led to misleading results in evaluation of the organic loading data. It was observed when biological activity was occurring that it was anaerobic and led to high pressure drops across the carbon bed. The biological activity occurred at the wastewater outlet section of the adsorption tower and disappeared when normal slugging of the carbon bed was started.

The data compiled during periods of what is described as typical or design operating conditions illustrate the effectiveness of the system for removal of wastes from the feed water. Typical operating periods were defined as times when carbon beds were being pulsed at design rates and the system wastewater feed quality was similar to that used for calculating design loading data. COD loadings of 0.9 lb COD per pound of carbon and TOC loadings of 0.38 lb TOC per pound of carbon were obtained during these periods. While in continuous service many design problems were discovered and corrective action taken to eliminate them. It was found that the pressure drop across the carbon bed was approximately 30% higher than design data. The reason was that activated carbon loaded with organics has different

TABLE 3. SECONDARY TREATMENT FEED AND EFFLUENT ANALYSES AND PERFORMANCE DATA

Item	Influent	Effluent	% Reduction	Removal lb/day
Design: (3.24 mgd)				
COD, mg/l	600	125	79	12,800
TOC, mg/l	160	30	81	3,500
BOD, mg/l	250	50	80	5,400
Start-up period: (2.592 mgd)				
COD, mg/l	975	152	84	17,800
TOC, mg/l	222	46	79	3,800
Typical operation: (2.592 mgd)				
COD, mg/l	752	160	79	12,800
TOC, mg/l	203	42	79	3,500
Selected samples: (2.592 mgd)				
BOD, mg/l	300	82	73	4,700
Phenols, mg/l	4.66	0.58	88	88
Ni, mg/l	1.02	0.33	68	15
Zn, mg/l	1.11	0.29	74	18
Cd, mg/l	0.91	0.22	76	15
Cu, mg/l	1.29	0.36	72	20
Cr, mg/l	1.12	0.26	77	19
TS, mg/l	1,211	965	20	5,300
SS, mg/l	81	13	84	1,500
DS, mg/l	1,130	952	16	3,800
Chlorides, mg/l	1.82	0.84	48	19
NO_2, mg/l	5.16	4.28	17	19
Oil and grease, mg/l	28.1	2.2	92	560

TABLE 4. TYPICAL TOTAL TREATMENT SYSTEM PERFORMANCE DATA (@ 2.592 mgd)

Parameter	Raw Waste Water (mg/l)	Primary Treated Effluent (mg/l)	Secondary Treated Effluent (mg/l)	Overall Reduction (%)
COD	3,200	670	143	95.5
TOC	1,200	198	37	96.9
BOD	1,600	267	73	95.4
SS	320	72	12	96.3
Oil and Grease	500	25	2	99.6

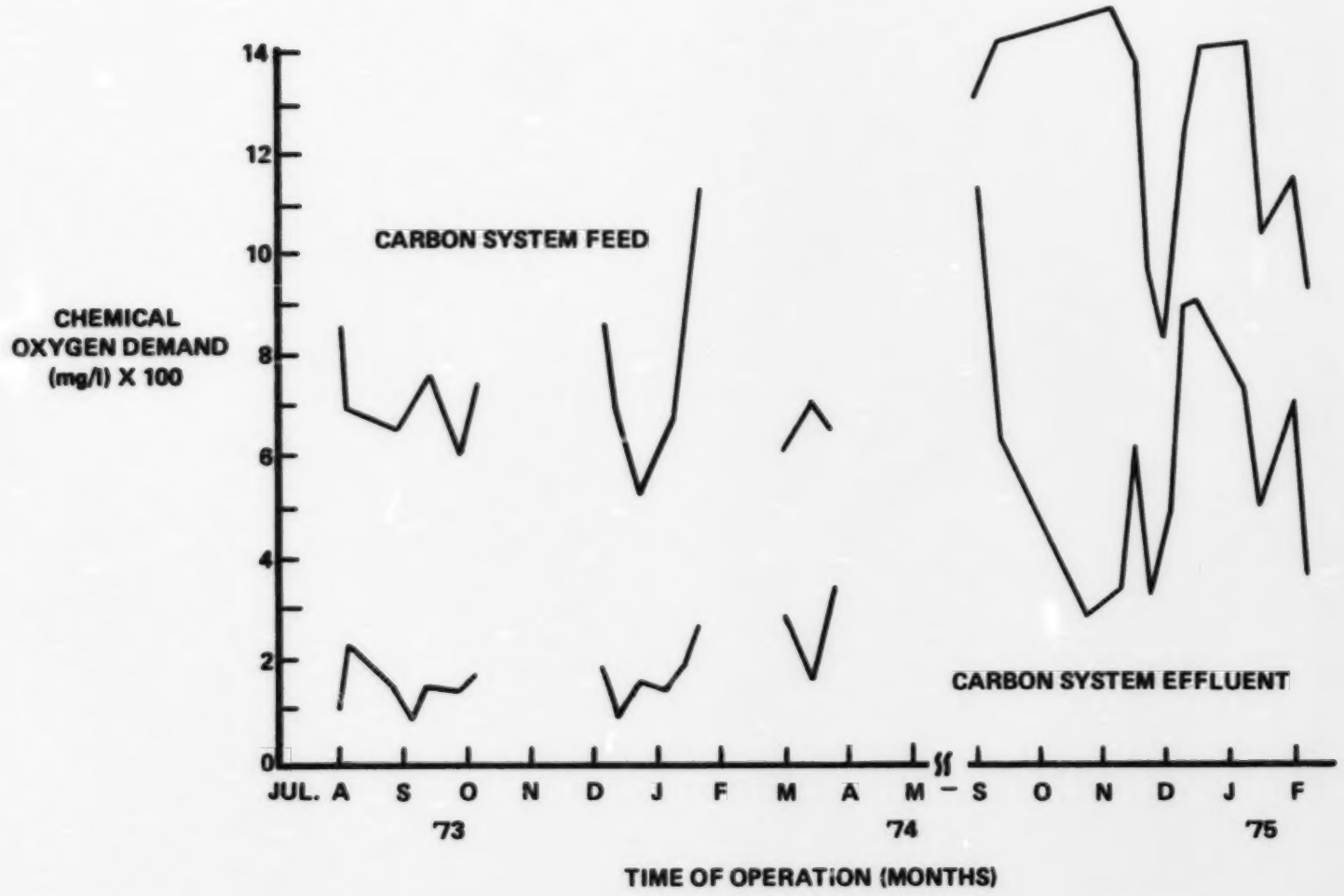

Figure 7. Carbon adsorption unit performance.

pressure drop characteristics than virgin carbon. To counteract this problem it would be necessary to design the carbon adsorption tower to withstand higher operating pressures. In the case of this unit the only solution was to pulse the bed more often to reduce the organic loading on the carbon bed especially since the organics form an oily, greasy film on the carbon surface. When evaluating the oil and grease content of the feed wastewater, it was found that for concentrations of less than 15 mg/l, the pressure drop across the bed was reduced to within operating limits, but if it was higher, the flow through the adsorber had to be reduced to lower the bed pressure drop. Other than the pressure drop problem, the adsorption system operated as anticipated when organic loadings and other operating conditions were near design values.

The carbon system was also operated during periods when the feed quality and system operating procedures were not typical as shown in Figure 7. Nevertheless COD and TOC removals still ran approximately 50%.

It was found during periods when the carbon bed was not pulsed on a routine basis that excessive bed pressure drops occurred and that effluent water quality deteriorated very quickly. During these periods, it was observed that anaerobic bacteria became very active in the top of the carbon bed. Another parameter of the system feed, pH, was found to have a tremendous effect on the quality of effluent from the carbon bed. It was found that if the pH of the system feed exceeded 9.0, the effluent water quality was reduced as much as 50% and it took several days of pulsing the carbon bed (depending on how high the pH was above 9.0) to restore its treatment efficiency. The most significant effluent water quality deteriorations, however, occurred as a result of inadequate primary treatment. Carbon regeneration capacity sets a definite limitation on system overload capacity. The furnace capacity rating of 33,600 lb/day compared to design carbon consumption of 21,000 lb/day would indicate an overload capability of 60%. This capability could probably be realized if the overload was dissolved organics. Our primary treatment difficulties, however, often resulted in excessive oil and grease levels which coated the carbon surface with an oily greasy film at rates which could not be matched by the regeneration furnace.

The reactivated carbon produced by the multiple hearth furnace is actually more effective than virgin carbon for treatment of the plant wastewater. Laboratory isotherms comparing the reactivated carbon to virgin carbon indicate an average reactivation efficiency of 104%. In discussing these results with various carbon manufacturers they indicated the reason for these results was that the very small pore sizes of the virgin carbon were not utilized in treatment of our plant effluent and after reactivation, the carbon contained a higher percentage of the larger pores and fewer of the small pores. This condition develops because the smaller pore openings are more easily fractured during the reactivation process to larger sizes. The carbon losses through the furnace system and carbon handling facilities are averaging from 3-5 per cent depending on the maximum furnace temperature. Typical operation is to fire the Number 5 hearth to a temperature of 1,650°F., and to only fire the Number 3 hearth when the temperatures of the remaining hearths drop below normal for the existing carbon feed rate and organic loading.

Data presented in Table 2-A (Appendix) indicate significant removals of phenols and certain metals by the carbon adsorption system. Also in this Table, the data show increases in nitrogen (ammonia) in all samples analyzed and in nitrogen (nitrate) in about half of the samples upon passage through the carbon system. We do not presently have an explanation for these increases.

ECONOMIC EVALUATION

The costs for operation of the carbon adsorption wastewater treatment system are summarized in Table 5.

TABLE 5. HATTIESBURG SECONDARY WATER TREATMENT COSTS
7/1/73-1/31/75

Item	Actual avg. cost/month	Grant forecast
Operation:		
Labor (incl. wage benefits)	$ 2,304	$ 4,062
Chemical control	537	*
Supervision	81	274
Overhead	1,909	*
Subtotal	4,831	4,336
Maintenance:		
Labor (incl. wage benefits)	4,262	4,116
Materials	3,357	2,150
Subtotal	7,619	6,266
Utilities:		
Electricity	4,153	875
Natural gas	675	5,886
Steam	-0-	441
Subtotal	4,828	7,202
Activated carbon**	12,908	10,243
Grand total	30,186	28,047
Treatment cost***	0.314	0.292

*Cost not anticipated in forecast.
**Actual carbon usage/month was 33,273 lb; forecast was 32,010 lb.
***$/1000 gal, @ 96 X 10^6 gal/month.

The operating cost for the treatment system is slightly higher than forecast due to several minor items. No allowances were made in the forecast for chemical (analytical) control of the operating system or for overhead as charged in the plant accounting system. A lower than forecast operating labor cost partially offset these charges since the number of operating personnel required was less than forecast.

The maintenance costs for the system were higher than the forecast amount due to replacement of many process lines constructed of carbon steel pipe with stainless steel, replacement of the laterals in the mixed media filters and various minor alterations in the equipment design.

The utilities cost was lower than forecast due to a reduced consumption of natural gas since it was found unnecessary to fire both hearths in the carbon reactivation furnace for proper operation, however, the electrical requirements for the treatment system were found to be higher than anticipated which partially offset the reduction in cost by reduced natural gas consumption.

The activated carbon consumption was slightly higher than forecast due to losses that occurred when recovering carbon that was contaminated with garnet when the laterals in the mixed media filters ruptured and to price increases in the carbon cost.

In summary, the treatment cost for the carbon adsorption facility was very near anticipated values (29.8¢/1000 gal) and averaged 31.4¢/1000 gal of water treated. During steady state operating periods when the wastewater feed was similar to design quality a COD removal cost of 6¢/lb was achieved. On the average, however, actual cost was about 8¢/lb of COD.

The carbon adsorption system required a capital investment of $1,422,000. Depreciation of this investment is distributed to the individual production accounts through the plant overhead account. The plant is not apprised of the rate, but 10%/year would amount to $142,200/year, $11,850/month, 15¢/1000 gal of water treated, or 3¢/lb of COD removed.

WATER REUSE

An activated carbon adsorption water treatment system requires an adequate supply of water for the various carbon transfer operations and for the scrubbing of offgases from the carbon reactivation furnace.

The water supply for scrubbing the off-gases from the carbon reactivation furnace is provided from the secondary treatment system feed pumps since the level of dissolved organics in the water has no appreciable effect on the operation of the scrubbing tower. The water appears to be satisfactory for this use although it is necessary to clean the scrubber trays periodically due to the oil and grease in the water condensing out of the trays and plugging them.

Effluent from the adsorption towers is used to proved the motive water for the various carbon transfer operations. This water so far has been of adequate quality to serve this purpose although there have been problems at times when carbon fines were discharged from the adsorption towers after the bed was pulsed. No other applications for recycle of this water have been evaluated to date, although several possibilities are under consideration. These include use in contact condensers, vent scrubbers, and cooling tower makeup.

SECTION V

REFERENCES

1. Skolnik, H., H. I. Enos, Jr., F. H. Gardner, Jr., The Literature of Wood Naval Stores. In Advances in Chemistry Series, Number 78, Literature of Chemical Technology, Gould, R. F. (ed.). American Chemical Society, Washington, D. C., 1968. pp. 349-361.

2. Grantham, B. J., Completion Report of Pollution Studies on the Leaf River. Fisheries and Pollution Division of Mississippi Game and Fish Commission, Jackson, Miss., Project F-9-R. May 1, 1961-April 30, 1962. p. 14.

3. Pascagoula River Basin Water Quality Management Plan. Pat Harrison Waterway District. Hattiesburg, Miss., June 1973. Vol. I, Chapter VI, pp. 256-257 and Vol. II, Chapter III, p. 45.

4. Risso, J. L., and R. E. Schade. Secondary Treatment with Granular Activated Carbon. Water and Sewage Works. Vol. 116, p. 307, August 1969

5. Process Design Manual for Carbon Adsorption, U. S. Environmental Protection Agency, Technology Transfer Office, 1973.

SECTION VI

APPENDICES

A. Laboratory Methods

Laboratory determinations were carried out by the procedures described in:

American Public Health Association, American Waterworks Association, and Water Pollution Control Federation, "Standard Methods for the Examination of Water and Wastewater", 13th Edition, American Public Health Association, Inc., New York, 1971.

The methods used were:

Ammonia--p. 453
Biological Oxygen Demand--p. 489
Cadmium--p. 422
Chemical Oxygen Demand--p. 495
Chlorides--p.376
Chromium--p. 426
Copper--p. 163
Dissolved Solids--p. 291
Nickel--p. 493
Nitrates--p. 454
Oil and grease--p. 254
pH--p. 500
Phenols--p 501
Suspended Solids--p. 290
Total Organic Carbon--p.257
Total Solids--p. 288
Zinc--p. 444

B. Detailed Data

Data on many of the days of operation of the water treatment facilities are listed in the following Tables. Samples analyzed were 24-hour composite samples made up of a minimum of four individual grab samples. Composites were not specifically flow proportioned because the streams sampled flow at relatively uniform rates.

TABLE 1-A. OPERATION OF WASTEWATER TREATMENT FACILITIES
DAILY COMPOSITE SAMPLES (1/DAY)

	Primary Treatment Effluent			Secondary Treatment Effluent			% Removal	
Date	pH	COD (mg/l)	TOC (mg/l)	pH	COD (mg/l)	TOC (mg/l)	COD	TOC
Startup no slugging:								
7/30/73 *	9.0	848	191	9.1	101	21	88	89
7/31	10.0	2520	350	9.9	95	20	96	94
8/1	7.5	1360	266	7.6	185	74	86	72
8/2	6.4	800	230	7.0	176	68	78	70
8/3	6.7	592	178	6.7	276	71	53	60
8/28	6.3	540	173	7.0	120	27	78	84
8/29	7.0	688	211	6.9	184	34	73	84
8/30	6.8	640	189	7.5	100	48	84	75
8/31	7.0	784	209	7.2	131	49	83	77
Typical operation but high feed:								
9/4	8.0	704	221	7.4	72	50	90	77
9/5	7.3	704	233	7.1	134	26	81	89
9/7	8.1	648	191	7.2	112	32	83	83
9/25	6.9	560	168	7.2	142	43	75	74
9/26	7.9	641	192	7.0	156	49	76	74
10/1	6.8	720	149	6.8	166	31	77	79
10/2	6.8	576	183	7.0	162	47	72	74
10/3	7.1	640	169	6.8	192	44	70	74
10/4	6.0	1077	200	6.5	189	48	82	76
10/5	6.9	1220	210	6.5	261	75	79	64
12/5	6.0	800	221	7.3	160	34	80	85
12/6	6.0	960	265	7.2	212	60	78	77
12/10	7.4	688	175	7.4	88	22	87	87
12/17	6.0	624	167	7.0	128	31	79	81
12/19	7.2	448	171	6.6	188	34	58	80
12/20	7.2	875	300	7.1	160	33	82	89
Very erratic slugging operation when operating:								
1/4/74	7.4	656	231	7.1	144	63	78	73
1/8	7.0	752	255	7.0	92	51	88	80
1/14	5.9	1136	295	6.3	272	64	76	78
1/15	6.3	---	680	6.6	---	84	---	88
2/15	6.6	1088	244	6.7	372	92	66	62
3/1	6.1	608	125	7.2	292	66	52	47
3/12	6.1	---	137	6.8	128	50	---	64
3/13	5.8	464	209	6.4	128	51	72	76
3/15	5.6	966	205	6.8	220	57	77	72
3/18 *	10.5	880	324	8.0	388	79	56	76
3/19	5.7	---	200	8.0	381	83	---	59
3/20	5.9	768	184	7.4	372	87	52	53
3/21	6.0	---	151	7.1	209	55	---	64

TABLE 1-A, CONTINUED. OPERATION OF WASTEWATER TREATMENT FACILITIES
DAILY COMPOSITE SAMPLES (1/DAY)

Date		Primary Treatment Effluent pH	COD (mg/l)	TOC (mg/l)	Secondary Treatment Effluent pH	COD (mg/l)	TOC (mg/l)	% Removal COD	% Removal TOC
Unit operated with little or no slugging:									
6/5		6.0	1360	194	8.0	1024	150	25	23
6/13		7.2	1168	520	7.4	976	406	16	22
6/17		5.8	1088	243	7.4	896	202	18	17
Slugging rate increased:									
7/6		6.0	876	231	7.0	440	118	50	49
7/11		6.4	1216	222	7.0	704	132	42	41
7/18		8.3	1472	194	7.5	1008	157	32	19
7/22		5.2	1744	307	7.0	720	109	59	64
7/28		6.1	496	221	7.0	192	148	61	33
8/15		6.4	688	364	8.6	560	260	19	29
8/21		6.3	1616	712	7.7	508	310	62	56
9/3		6.4	1312	288	7.7	1136	235	13	18
9/12		6.3	1424	336	7.1	624	159	56	53
10/27		6.4	1904	333	8.1	288	91	85	73
11/5		4.1	1472	312	7.6	336	85	77	73
11/14		6.2	1397	405	6.8	647	281	54	31
11/21		7.8	944	240	7.4	304	94	68	61
12/3		6.9	838	247	7.8	456	143	46	42
No slugging:									
12/10	*	8.9	1200	278	8.8	896	224	25	19
12/17		7.3	1408	337	8.2	955	216	32	36
1/6/75	*	8.7	1424	844	8.7	734	209	48	39
1/14	*	9.4	1040	367	8.9	496	137	52	63
1/21		7.5	1540	368	7.6	848	232	45	37
1/29		6.4	1168	252	7.1	736	88	37	65
2/4		7.6	926	240	7.3	368	100	60	58
2/12	*	9.3	1472	345	9.2	976	240	34	30

*Denotes periods of high pH

TABLE 2-A. DAILY COMPOSITE SAMPLES (4/DAY): ANALYSES OF CARBON TREATMENT SYSTEM FEED AND PRODUCT (mg/l EXCEPT pH AND TEMPERATURE)

Date	Sample*	pH	COD	BOD	TOC	T.S.	D.S.	S.S.	Oil & Grease	Phenols	N (NH_3)	N (NO_3-)	Ni	Zn	Cd	Cu	Cr	Cl	Temp. °C.
7/22/74	P.T.E.	5.2	1744	792	307	1304	1268	36	352										38
	S.T.E.	7.0	720	285	109	1078	1054	24	54										38
	% Rem.	-	59	64	64	17	17	33	85										-
8/21	P.T.E.	6.3	1616	840	712	131	111	20	95										34
	S.T.E.	7.7	608	330	310	121	119	2	1										34
	% Rem.	-	62	61	56	8	-7	90	99										-
9/12	P.T.E.	6.3	1424	-	336	1040	916	124	60										32
	S.T.E.	7.1	624	-	159	842	814	28	8										32
	% Rem.	-	56	-	53	19	11	77	87										-
10/19	P.T.E.	6.4	1451	541	427	1265	1129	136	52	3.25	31.4	8.56	1.08	1.32	0.96	1.98	1.32	1.91	33
	S.T.E.	7.4	496	301	259	695	689	6	6	0.22	35.0	7.71	0.56	0.41	0.14	0.43	0.19	0.44	33
	% Rem.	-	66	44	39	45	39	96	88	93	-11	10	48	69	85	78	86	77	-
10/27	P.T.E.	6.3	1521	441	321	1335	1139	196	139	7.23	28.3	6.04	0.98	1.07	0.89	1.15	1.06	1.42	33
	S.T.E.	7.8	246	104	88	680	672	8	20	0.39	30.3	4.73	0.19	0.11	0.09	0.23	0.13	0.58	33
	% Rem.	-	84	76	73	49	41	96	86	95	-7	22	81	90	90	80	88	59	-
11/5	P.T.E.	7.3	1399	583	307	1800	1748	52	49	5.73	12.8	7.31	1.13	1.41	0.94	1.54	1.16	1.91	31
	S.T.E.	7.5	289	114	91	1643	1639	4	3	0.20	21.7	5.04	0.36	0.33	0.19	0.49	0.28	1.01	31
	% Rem.	-	79	80	70	9	6	92	94	97	-70	31	68	77	80	68	76	47	-
11/14	P.T.E.	6.2	1397	576	405	1374	1274	100	108	8.83	26.6	8.21	1.03	1.44	1.14	1.46	1.27	2.08	29
	S.T.E.	6.8	648	325	281	1116**	1042	74**	31	2.30	37.0	4.86	0.32	0.41	0.29	0.48	0.37	1.43	29
	% Rem.	-	54	44	31	19	18	26	71	74	-38	41	69	72	75	67	71	31	-
11/21	P.T.E.	7.7	914	686	189	956	908	48	134	6.05	26.8	2.41	1.51	1.21	0.91	1.15	1.42	1.96	28
	S.T.E.	7.7	298	274	88	908	894	14	32	0.94	37.1	3.02	0.61	0.48	0.29	0.41	0.33	1.14	28
	% Rem.	-	67	60	53	5	2	71	76	84	-38	-25	60	60	68	64	77	42	-
12/3	P.T.E.	6.9	838	515	202	1348	1310	38	32	1.67	4.8	2.48	0.83	0.98	1.09	1.17	1.01	2.04	28
	S.T.E.	7.8	456	318	151	1120	1116	4	3	0.42	9.7	3.31	0.19	0.17	0.44	0.34	0.21	1.00	28
	% Rem.	-	46	38	25	17	15	89	91	75	-102	-33	77	83	60	71	79	51	-
1/6/75	P.T.E.	8.6	1397	504	346	1980	1906	74	44	0.29	3.81	1.12	0.61	0.33	0.46	0.61	0.63	1.43	28
	S.T.E.	8.5	736	313	205	2052	2016	36	24	0.03	4.32	1.31	0.09	0.11	0.07	0.16	0.28	1.01	28
	% Rem.	-	47	38	41	-4	-6	51	45	90	-13	-17	85	67	85	74	56	29	-
2/4	P.T.E.	7.6	926	524	240	786	716	70	21	4.21									30
	S.T.E.	7.3	348	180	100	512	508	4	3	0.12									30
	% Rem.	-	62	66	58	35	29	94	86	97									-
Average	P.T.E.	6.8	1330	600	345	1211	1130	81	99	4.66	19.2	5.16	1.02	1.11	0.91	1.29	1.12	1.82	31
	S.T.E.	7.5	497	254	167	979	960	19	17	0.58	25.0	4.28	0.33	0.29	0.22	0.36	0.26	0.94	31
	% Rem.	-	63	58	52	19	15	77	83	88	-30	17	68	74	76	72	77	48	-

*P.T.E. = Primary treatment effluent.
S.T.E. = Secondary treatment effluent.
% Rem. = % Removed.
**Carbon fines in sample.

SECTION VII

GLOSSARY

BOD	Biochemical oxygen demand; an empirical bio-assay type procedure which measures the dissolved oxygen consumed by microbial life while assimilating the organic matter in the water sample. Usually listed as BOD_5, this test is conducted for a 5-day period to measure the pollutional strength.
Cd	Cadmium.
Chlorides	Chloride content.
COD	Chemical oxygen demand; a measure of pollutional strength determined by chemically oxidizing the organic and oxidizable inorganic substances.
Cr	Chromium.
Cu	Copper.
DS	Dissolved solids; nonfiltrable residue.
mg/l	Milligrams per liter (essentially equivalent to ppm).
NH_3	Nitrogen; ammonia.
Ni	Nickel.
NO_3-	Nitrogen; nitrate.
pH	The negative logarithm of the hydrogen ion concentration; a measure of the functional acidity of alkalinity of a liquid.
Phenols	Measurement of phenolic compounds in a water sample.
ppm	Parts per million.
SS	Suspended solids; filtrable residue.
TOC	Total organic carbon; a measure of the organic carbon content of a water sample by catalytic combustion of the carbon to CO_2.
TS	Total solids; sum of filtrable and nonfiltrable residue.
Zn	Zinc.

METRIC CONVERSION CHART

Multiply	By	To get
Inches	2.54	Centimeters
Feet	0.3048	Meters
Square feet	0.0929	Square meters
Cubic feet	0.0283	Cubic meters
Pounds	0.454	Kilograms
Gallons	3.79	Liters
Gallons/minute	5.458	Cubic meters/day
Feet/second	0.305	Meters/second